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Analyzing Measures for the Construct "Energy-Conscious Driving": A Synthesized Measurement Model to Operationalize Eco-Feedback

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Abstract

During the last several years, a large number of studies have dealt with eco-driving and have defined rules for driving vehicles more ecologically, eco-friendly, and energy efficiently. These rules are vague or insufficient for achieving their purpose, and the construct "energy-conscious driving" is unsatisfactorily defined. To structure available research and develop a more extensive concept of energy-conscious driving, a measurement model for energy-conscious driving is introduced. The model stems from a literature review conducted to identify six groups of measures for energy-conscious driving, and a synthesis of these groups to identify dependencies between them. This paper contributes to theory by building on existing knowledge on eco-driving through an analysis of available literature and describing dependencies between our six measures of energy-conscious driving. Based on our model, researchers can evaluate different eco-feedback designs and practitioners can implement more specific eco-feedback systems for improved user performance.

Keywords: Eco-driving, energy-conscious driving, Green IS measurement model, operationalization of eco-feedback

Introduction

Climate change increases the interests of information systems (IS) research (Gholami et al. 2016; Malhotra et al. 2013; Seidel et al. 2015; Watson et al. 2010; Watson et al. 2012). Green IS addresses the threat through the use of more sustainable energy consumption and enables energy-conscious driving (Gholami et al. 2016). Therefore, this study focuses on an analysis of measures for the construct "energy-conscious driving" that contribute to concepts for eco-driving. Eco-driving is a short form for economical and ecological driving; and in this paper, we understand it as operational decisions, such as driving behavior, that improve vehicle fuel economy (Sivak and Schoettle 2012). Eco-feedback influences eco-driving and is a technology providing feedback on drivers' behavior to reduce the environmental impact of operating a motor vehicle (Froehlich et al. 2010). Designing eco-feedback for energy-conscious driving is challenging: in addition to the primary driving task (Kern and Schmidt 2009), the vehicle's energy consumption needs cognitive workload from the driver (Donmez et al. 2007; Manner et al. 2013; Salvucci et al. 2001; Sethumadhavan 2011). Measures for energy-conscious driving are necessary for green IS advanced driver assistance systems, which are a key technology needed to change human behavior to aim for more energy efficient driving styles (Loock et al. 2013; Watson et al. 2010). Human behavior has a significant impact on energy consumption (Evans 1979; McIlroy et al. 2013). Hence, designing eco-feedback for energy-conscious driving requires intensive study of driving behavior.

Eco-driving rules address this behavior. However, some of these rules are vague such as *shifting up as soon as possible* (Beusen et al. 2009) or *shift down late* (Kaufmann-Hayoz et al. 2012), while other studies present more concrete measures, such as calculating an optimal acceleration pedal angle (Jamson et al. 2015; Wada et al. 2011). Further, energy-conscious driving is unsatisfactorily defined. Therefore, we need a classification schema to structure this area of research and develop a broad Green IS concept of energy-conscious driving.

Therefore, the purpose is to analyze measures for energy-conscious driving as preparation for experiments in order to evaluate various designs of eco-feedback and driving behavior. Our paper aims to apply this knowledge for the operationalization of energy-conscious driving. To reach this aim, we pursue the research question: What measures are used for designing Green IS solutions for energy-conscious driving?

We structure this article as follow, in the Method section we describe the literature review and the procedure for grouping energy-conscious driving measures. In the Analyzed Literature, Groups of Measures and Synthesis of Measures sections, selected literature is synthesized and analyzed according to the identified measures. We discuss our findings in the Discussion section before we conclude this article and discuss the implications for future research in the Conclusion, Limitations and Future Research section.

Method

To identify measures for energy-conscious driving, we apply a two-step approach.

In the *first step*, we used the paradigm from vom Brocke et al. (2009) and conducted a forward and backward search according to Webster and Watson (2002). Therefore, this article goes from an author-centric to a concept-centric approach. To identify relevant literature in the field of information systems, we considered the “Senior Scholars' Basket of Journals” to assure a high quality of research. Also, we reviewed information systems-specific literature presented at conferences, such as those on human-computer interaction (*CHI*, *SIGCHI)* and the design of computer systems (*AutomotiveUI)* (Kern and Schmidt 2009; Petkov et al. 2012; Petkov et al. 2011; Stern 1992; Stern 2000). We considered the area of *Transportation Research (TR)* as suitable for this research (Staubach et al. 2012), and we include the journals: *TR Part C*, *TR Part D,* and *TR Part F.* We searched the databases: *EBSCOhost*, *IEEE Xplore*, *ACM Digital Library*, and *scholar.google* using the keywords *eco**, *energy efficient*, *driving,* and combinations of these words. Due to the tremendous amount of literature (7,793 articles) found by scholar.google, we limited the search after the first 150 findings. In order to limit the findings to those applicable to our research question and relevancy, we looked at (1) title, (2) keywords and (3) abstract of the selected articles, and then ranked them by the presented order. Finally, we selected 32 relevant articles from journals and conferences and included them in the review (see Table 1). To identify and rank these relevant articles, we use the coding schema from the second step (see Table 1: row sum greater than one).

In the *second step*, we used the findings from the first step to identify a coding schema; these findings indicate rules for eco-driving. The rules for eco-driving obtained from these literature sources are, however, somewhat vague. From these vague phrases we derived codewords; each codeword stands for a specific group of measures used as the basis for the coding schema to conceptualize the findings. Therefore, we synthesized the literature in a concept-centric way (Webster and Watson 2002). For the synthesis, we coded the literature binary with zero and one. If the finding in the literature fit a coded group of measures, it was marked with one, otherwise with zero (see Table 1). More specifically, we focused on applied measures because only naming the influence of the group of measures is insufficient (marked with zero). We used binary coding to measure the impact of the group of measures and to identify the coverage of groups by a particular article. We totaled the entries for each row and each column to a sum. We ranked that column sum to absolute frequency. The higher the rank, the greater the number of groups covered by the article. An article was not relevant when the sum of covered groups is zero (row sum). Correspondingly, the row sum was ranked according to the absolute frequency. The higher the rank, the higher was the number of articles applying the certain measure of the group. Contrastingly, a lower rank indicates less use of groups. Further, we considered the groups of measures themselves. We first defined the group, then analyzed related eco-driving rules, and lastly identified methods of measurement. In addition, we studied the implementation of these measures regarding the design of eco-feedback. Subsequently, we analyzed dependencies and interrelations between each group of measures. Finally, we synthesized the findings in a measurement model for energy-conscious driving.

Analyzed Literature

After conceptualizing the literature, we used the vague rules found on eco-driving to identify coding words. Beusen et al. (2009) determine four "golden rules" of eco-driving: (i) shifting up as soon as possible, (ii) using the highest gear possible and driving at low engine speed, (iii) maintaining a steady speed by anticipating traffic flow, and (iv) decelerating smoothly while leaving the car in gear. Two rules identified by Kaufmann-Hayoz et al. (2012) extend these four rules: (v) shift down late, and (vi) accelerate swiftly. These rules are confirmed by Neumann et al. (2015) who look at accelerating, braking and eco-driving behavior. Their rules include: avoid high speeds, accelerate moderately, drive evenly (speed and acceleration), use regenerative braking/avoid braking, choose anticipatory driving style, avoid auxiliary functions, drive in a way that the instantaneous power meter indicates low energy consumption, let the car coast (sailing), choose the most energy-efficient route to destination, choose optimal tires/tire pressure, minimize load, and avoid driving short distances (Neumann et al. 2015). From these six rules, we extract the following groups for coding: *anticipatory driving* (rule iii), *speeding* (rule iii), *gear shifting* (rules i, ii, iv, and v), *accelerating* (rule vi), *decelerating* (rule iv), and *engine speed* (rule ii). Table 1 conceptualizes our findings according to the groups: (1) *anticipatory driving*, (2) *speeding*, (3) *gear shifting*, (4) *decelerating*, (5) *accelerating* and (6) *engine speed*.

Table 1. Concept Matrix

Autor	Anticipatory driving	Speeding	Gear Shifting	Accelerating (Cruising/ Non-cruising)	Decelerating (Active/Passive)	Engine Speed	Sum
Álvarez et al. (2014)	0	1	0	1	1	0	**3**
Ando and Nishihori (2011)	0	0	0	1	1	0	**2**
Andrieu and Saint Pierre (2014)	1	1	1	1	1	1	**6**
Azzi et al. (2011)	0	0	0	1	0	0	**1**
Barbé et al. (2007)	0	1	1	0	0	0	**2**
Barkenbus (2010)	1	1	1	1	1	1	**6**
Barth and Boriboonsomsin (2009)	0	1	0	0	0	0	**1**
Beusen et al. (2009)	0	1	1	1	1	1	**5**
Bingham et al. (2012)	0	0	0	1	1	0	**2**
Boriboonsomsin et al. (2010)	0	1	0	1	0	0	**2**
Caulfield et al. (2014)	0	0	0	1	1	0	**2**
Cho (2008)	0	0	0	1	1	0	**2**
Cristea et al. (2012)	0	1	0	0	0	0	**1**
Dahlinger and Wortmann (2016)	0	0	1	1	0	1	**3**
Dogan et al. (2011)	1	1	1	1	1	1	**6**
Ericsson (2001)	0	1	1	1	1	1	**5**
Evans (1979)	1	1	0	1	1	0	**4**
Ford Motor Company (2016)	0	0	0	1	0	0	**1**

Harvey et al. (2013)	0	0	0	1	1	0	**2**
Helmbrecht et al. (2014)	1	1	0	1	1	0	**4**
Hiraoka et al. (2009)	0	0	0	1	0	1	**2**
Jamson et al. (2015)	0	0	0	1	0	0	**1**
Kaufmann-Hayoz et al. (2012)	1	0	1	1	1	1	**5**
Kircher et al. (2014)	1	1	0	1	1	0	**4**
Magaña and Munoz-Organero (2011a)	1	1	1	1	1	1	**6**
Magaña and Munoz-Organero (2011b)	0	1	0	1	1	1	**4**
Neumann et al. (2015)	0	1	0	1	0	1	**3**
Pace et al. (2007)	0	0	0	1	1	0	**2**
Rommerskirchen et al. (2013)	1	0	0	0	0	0	**1**
Saboohi et al. (2009)	0	1	1	0	0	1	**3**
Sivak and Schoettle (2012)	0	1	0	0	0	1	**2**
Wada et al. (2011)	0	0	0	1	0	0	**1**
Sum	**9**	**18**	**11**	**26**	**18**	**12**	

Groups of Measures

In the following sections, we provide definitions for the six groups of eco-driving measures and analyze how to classify and measure them.

Anticipatory driving is the least applied measure for eco-driving in the literature we analyzed. However, compared to the other five groups (speeding, gear shifting, accelerating, decelerating, and engine speed), it has been more recently discussed. An anticipatory driving style (driving with foresight) is characterized by looking ahead as far as possible and anticipating the surrounding traffic (Andrieu and Saint Pierre 2014), traffic events (Cristea et al. 2012), and signals (Barkenbus 2010). Anticipatory driving helps the driver to avoid sudden (Barkenbus 2010) and unnecessary (strong) braking, and accelerating and gear-shifting maneuvers (Kaufmann-Hayoz et al. 2012). It could be supposed that anticipatory driving supports the driver in maintaining a constant speed, i.e. cruising (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Rakotonirainy et al. 2011) and in minimizing braking (Evans 1979), resulting in reducing energy loss, since braking has been identified as wasting energy (Kircher et al. 2014; Saboohi and Farzaneh 2009).

Anticipatory driving also influences speeding (which for our purposes refers to the limitation of the speed of travel or velocity). Forward-looking drivers can anticipate situations in which temporary speed reduction might lead to a reduction in braking and the number of stops (Evans 1979). As a result, there are less fuel consumption and energy loss. A specific experiment conducted in the United States supports this influence of anticipation on speed and on fuel consumption. According to the experiment, 70 ml of fuel can be saved by driving at a constant speed of 60 km/h through a signal instead of stopping to 0 km/h, idling for 30 seconds, and then accelerating to 60 km/h (Evans 1979).

Since anticipatory driving influences speeding, gear shifting, accelerating and decelerating, measuring it is quite tricky. Andrieu and Saint Pierre (2014) measure the positive kinetic energy to evaluate driving with foresight as they characterize anticipatory driving by the driver's ability to keep the kinetic energy of the vehicle as low as possible. According to these authors, kinetic energy close to zero characterizes smooth driving (Andrieu and Saint Pierre 2014). Indicators for an anticipatory driving style are: The gas pedal release distance, i.e. the distance between the point where easing up on the pressure on the gas pedal, the traffic light, and the brake pedal push distance, i.e. the distance between the point where the brake pedal is pressed and the traffic light (Dogan et al. 2011).

External sensors can partly measure anticipatory driving such as an orientation sensor senses the slope of the road, providing the opportunity to evaluate the appropriateness of gear-changing and braking behavior (Magaña and Muñoz-Organero 2011a). Additionally, anticipatory driving can increase energy efficiency by measuring the number of stops per kilometer at different speed intervals (Ericsson 2001).

Therefore, we do not consider eco-driving assistance as a separate group but subsume it under anticipatory driving. Anticipatory assistance systems encourage an anticipatory driving style, and help drivers to broaden their anticipation horizon to drive energy efficiently (Helmbrecht et al. 2014; Rommerskirchen et al. 2013). Therefore, the anticipatory assistance system recognizes upcoming events, such as changes in speed limits, and uses this knowledge to advise the driver to make use of the engine brake instead of actively braking in order to reduce fuel consumption (Helmbrecht et al. 2014; Kircher et al. 2014; Rommerskirchen et al. 2013).

Speeding, as used in this group, is related to the limitation of the traveling speed or velocity. Velocity is measured as the distance in ratio to time as measured in miles or kilometers per hour. This group does not address the velocity regarding acceleration and deceleration. 18 of the analyzed research papers applied speeding as a measure for energy-conscious driving. It is an influential factor for eco-driving and fuel consumption in general (Barth and Boriboonsomsin 2009; Saboohi and Farzaneh 2009). As more fuel is used at higher speed (Evans 1979; Kircher et al. 2014), energy can be saved by an average reduction in speed (Helmbrecht et al. 2014) and the avoidance of driving at high speed. Therefore, it is advised to avoid driving faster than necessary (Kircher et al. 2014). More precisely, recommendations are to comply with speed limits (Barkenbus 2010; Cristea et al. 2012), respectively to drive safely below the posted speed limit (Barkenbus 2010). A specific suggestion for Belgium, i.e., is to drive no faster than the highway speed limit (120 km/h) (Beusen et al. 2009). An implementation of this recommendation is an eco-driving assistance system that shows driver speed information only if they exceed the legal speed limit (Kircher et al. 2014). Driving under the speed limit aids in reducing energy consumption.

Regarding urban traffic, energy can be saved by increasing average velocity, as speed is usually below the optimal speed range while driving inside city limits (Evans 1979). Indeed, fuel consumption is an inverted-U-shaped function of speed and revolutions per minute (rpm) (Sivak and Schoettle 2012), whereby driving at 50-70 km/h (Ericsson 2001) or 60-70 km/h (Hiraoka et al. 2009) results in fuel efficiency. In order to choose the most eco-friendly speed, intelligent speed adaption systems are used (Barth and Boriboonsomsin 2009).

The speeding factor is generally measured by using the actual speed displayed on the speedometer (Kircher et al. 2014) or provided by Global Positioning System (GPS) sensors (Beusen et al. 2009; Helmbrecht et al. 2014), or the average velocity for a specific distance (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Dogan et al. 2011; Helmbrecht et al. 2014; Neumann et al. 2015). Additionally, Andrieu and Saint Pierre (2014) consider the percentage of time above the legal speed limit as a further variable to measure the effect on economical driving. The higher the value of this variable, the higher the energy consumption (Andrieu and Saint Pierre 2014). Hence, any velocity higher than the speed limit causes additional energy consumption (Kircher et al. 2014). Comparing traffic sign recognition or map data with the current velocity illustrates whether energy-conscious driving exists. The difficulty occurs when there is no posted speed limit. In this case, we suggest looking at the legally recommended speed limit for that type of road.

The group *gear shifting* includes all articles dealing with gears or shifting gears. Appropriately timed gear changes can achieve eco-driving (Ericsson 2001; Jamson et al. 2015). Driving in higher gears is recommended (Hiraoka et al. 2009)—more specifically, the highest gear possible (Beusen et al. 2009; Saboohi and Farzaneh 2009). Therefore, the literature suggests up shifting early (Kaufmann-Hayoz et al. 2012; Rakotonirainy et al. 2011), or as soon as possible (Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Saboohi and Farzaneh 2009).

Some authors specify an optimal engine speed range for up shifting. In general, the 2,000 to 2,500 rpm range is declared optimal (Andrieu and Saint Pierre 2014; Barkenbus 2010; Beusen et al. 2009). More precisely, Saboohi and Farzaneh (2009) identified an optimal speed at 1,930 rpm. Especially shifting from first gear to third gear should be done promptly, resulting in lower engine speed and lower friction losses (Saboohi and Farzaneh 2009). Furthermore, late gear changing from second and third gear result in above-average heavy fuel consumption (Ericsson 2001).

The instruction to "shift up early" is commonly measured as the average engine speed reached at the point when the transmission shifts into a higher gear (Andrieu and Saint Pierre 2014; Beusen et al. 2009;

Dogan et al. 2011). The selected gear can be calculated by analyzing the electronic engine data extracted from the CAN bus (Beusen et al. 2009). Unlike shifting up early, shifting down should be done as late as possible (Kaufmann-Hayoz et al. 2012).

The *accelerating* group refers to articles that understand acceleration as the increasing velocity of a particular speed A to a specific speed B, e.g., from 0 to 50 km/h. Accelerating is the most applied measure for eco-driving in the analyzed literature (Bingham et al. 2012; Cho 2008; Ericsson 2001; Evans 1979; Helmbrecht et al. 2014; Jamson et al. 2015; Pace et al. 2007; Wada et al. 2011). Groups of accelerating are: (i) cruising (cruising track jerk) and (ii) non-cruising (starting movement jerk) (Álvarez et al. 2014). Cruising means depressing the accelerator pedal to maintain constant speed; the stage of non-cruising is synonymous to the acceleration phase, which means incrementing acceleration to reach a higher speed from a distinct velocity level (Jamson et al. 2015). Regarding *cruising*, even driving behavior at steady speed is recommended (Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Barkenbus 2010; Barth and Boriboonsomsin 2009; Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Hiraoka et al. 2009; Neumann et al. 2015) since constant driving with less acceleration and less braking leads to less energy loss (lower energy consumption) (Ericsson 2001; Evans 1979; Helmbrecht et al. 2014; Neumann et al. 2015). Concerning *non-cruising*, accelerating smoothly but not too quickly (moderate or gentle acceleration) can reduce fuel consumption by about 15% (Barkenbus 2010; Barth and Boriboonsomsin 2009; Boriboonsomsin et al. 2010; Cho 2008; Evans 1979; Helmbrecht et al. 2014; Neumann et al. 2015; Saboohi and Farzaneh 2009). In contrast, Kaufmann-Hayoz et al. (2012) recommend swift acceleration. Hiraoka et al. (2009) point out national differences: whereas gentle acceleration is recommended in Japan, the German advice is to accelerate adequately to reach fuel-efficient velocity as soon as possible.

The most-widely applied variant for measuring acceleration is the angle of the accelerator pedal (Azzi et al. 2011; Beusen et al. 2009; Dogan et al. 2011; Ford Motor Company 2016; Jamson et al. 2015; Wada et al. 2011). The accelerator pedal has been identified as an influential factor in vehicle fuel consumption (Jamson et al. 2015). Jamson et al. (2015) recommend an optimum pedal angle of 7% while cruising, and 23% for the acceleration phase, given that 100% pedal angle means that the accelerator pedal is fully depressed. A signal on the dashboard aids the driver in choosing the right accelerator pedal angle. The signal is a green lamp and stands for a pedal error of ±1 % (proper pedal pressure), with a blue or red signal for a pedal error of more than -6% (insufficient pedal pressure), or +6 % (too much pedal pressure) (Jamson et al. 2015). Several car manufacturers provide the driver with real-time information concerning proper acceleration while taking the angle of the accelerator pedal (Ford Motor Company 2016; Harumoto et al. 2011; Inbar et al. 2011; Motonaga and Saito 2012). They measure how far the pedal is depressed and illustrate this with a bar showing the remaining distance (Ford Motor Company 2016; Inbar et al. 2011). Whereby, Wada et al. (2011) presented the visual scoring model for eco-driving and use the angle of the depressed acceleration pedal to measure eco-driving (Wada et al. 2011). They indicate eco-driving using a green signal and a vertical bar that shows the driver is driving in the eco-driving range. The smaller the vertical bar, the more a driver is driving eco-friendly (Wada et al. 2011).

Another variant consists of measuring the average over-acceleration by comparing the car's instantaneous longitudinal acceleration in real time with the optimal acceleration level of the car's speed. The optimal acceleration level is taken as given by the manufacturer's proprietary eco-driving rule (Azzi et al. 2011). The difference of these measures shows if and how much the driver over-accelerates. While using a haptic pedal system, over-acceleration can be counteracted by raising the pedal's resistive force, guiding the driver to accelerate adequately (Azzi et al. 2011; Jamson et al. 2015). In addition, alternatives to measuring economically efficient accelerating measures: the speeding time (Caulfield et al. 2014); the percentage time of heavy acceleration, i.e. an acceleration greater than 1.5 ms^{-2} (Beusen et al. 2009); the consideration of intensity, frequency and time of acceleration (Magaña and Muñoz-Organero 2011b), and the external variables by installing an acceleration sensor outside of the vehicle (Magaña and Muñoz-Organero 2011a).

The group *decelerating* stems from deceleration and this is defined as decreasing the velocity of a specific speed C to a specific speed D, e.g., from 60 to 30 km/h. However, before a vehicle decelerates, a speed greater than zero needs to be reached as Neumann et al. (2015) confirm. In the analyzed literature, we identify two types of decelerating: (i) active and (ii) passive. *Active decelerating* is depressing the brake pedal, and it slows down the car through use of a specific brake mechanism. Active decelerating causes energy loss that is no longer available to the car, and the driver needs to avoid this action (Ericsson 2001; Kircher et al. 2014; Saboohi and Farzaneh 2009). *Passive decelerating* is defined as releasing the accelerator pedal (coasting), and using the engine brake or regenerative braking (Beusen et al. 2009; Hiraoka et al. 2009; Kircher et al. 2014). Regenerative braking is a state before active braking slows the car down, more specific before the brake pads hit the brake discs and do not cause energy loss. Therefore we group regenerative breaking as a subgroup of passive deceleration.

Drivers are recommended to decelerate smoothly (gradual) and avoid harsh braking in order to reduce fuel consumption (Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Helmbrecht et al. 2014; Jamson et al. 2015; Pace et al. 2007; Saboohi and Farzaneh 2009). Smooth deceleration is defined as releasing the accelerator pedal in time while leaving the car in gear (Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Beusen et al. 2009; Hiraoka et al. 2009). Further suggestions are regenerative braking (Helmbrecht et al. 2014; Neumann et al. 2015) and active application of the engine brake (Hiraoka et al. 2009). Passive deceleration also includes coasting deceleration, and it consumes energy by driving while the transmission is not in gear (engine is in idle mode). The resistances of air or of rolling causes the deceleration. Kircher et al. (2014) present a coasting guide which shows the elevation profile of the road. Their coasting guide illustrates to the driver when to release the gas pedal and coast instead (Kircher et al. 2014).

Similar to accelerating, the angle of the brake pedal can measure the decelerating factor, which include: the extent to which the driver depresses the pedal, measured as a percentage (Dogan et al. 2011); the release of the accelerator pedal in time while having a gear selected (Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Beusen et al. 2009; Hiraoka et al. 2009); the percentage of time in engine brake (Andrieu and Saint Pierre 2014; Beusen et al. 2009); the average deceleration measured regarding ms^{-2} (Andrieu and Saint Pierre 2014; Dogan et al. 2011; Pace et al. 2007); and the percentage of time at massive deceleration, i.e., braking greater than 2.5 ms^{-2} (Beusen et al. 2009). Car manufacturer Toyota installs a brake operation sensor that detects how often the driver uses the brake pedal (Harumoto et al. 2011; Motonaga and Saito 2012).

The group *engine speed* refers to articles describing engine speed or engine throttle. The engaged gear influences the engine speed and is the motive of changing gear in an appropriate way (Andrieu and Saint Pierre 2014; Barbé et al. 2007; Dogan et al. 2011; Ericsson 2001). Adequate gear changing reduces engine speed (Ericsson 2001). The found measurements for the factor engine speed are the rpm (Beusen et al. 2009) or the average rpm (Andrieu and Saint Pierre 2014; Dogan et al. 2011).

It is recommended that the vehicle be operated at low engine revolutions per minute (Beusen et al. 2009; Hiraoka et al. 2009; Kaufmann-Hayoz et al. 2012) because high rpm increase fuel consumption (Magaña and Muñoz-Organero 2011b). The literature does not uniformly define optimal engine speed. Barbé et al. (2007) declare 2,500 rpm as too high, while Azzi et al. (2011) recommend not exceeding 2,000 rpm. Beusen et al. (2009) identify an engine speed between 1,100 and 1,700 rpm as optimal for steady speeds. Ericsson (2001) emphasizes the above-average positive impact of an engine speed greater than 3,500 rpm on fuel consumption (i.e., higher fuel consumption) and the negative impact of driving at moderate engine speed in second and third gear (i.e., less fuel consumption). The most frequently mentioned range lies between 2,000 and 2,500 rpm (Andrieu and Saint Pierre 2014; Barkenbus 2010). However, optimal engine speeds are specific to the vehicle and the context of the study. We found in the literature no universal, vehicle-independent optimal engine speed.

In addition to proper gear changing, driving slowly (at a reduced speed) can reduce high engine speeds (Ericsson 2001). Beusen et al. (2009) consider the percentage distance covered at optimal engine speed. Andrieu and Saint Pierre (2014) introduce the *IndexGearRPM*, a combined indicator of engine speed and selected gear, which roughly takes the average engine speeds for each possible gear multiplied by the percentage time in each gear (Andrieu and Saint Pierre 2014). Another measurement is the idling time, since energy consumption is higher when the car is left in idle mode instead of turning the engine off during a stop (Caulfield et al. 2014; Harvey et al. 2013; Pace et al. 2007; Saboohi and Farzaneh 2009; Sivak and Schoettle 2012). As a result, the idling of the engine is a specific engine speed.

Synthesis of Measures

The analyzed literature used specific measures for their research. We synthesize these measures to develop a Green IS measurement model for the constant "energy-conscious driving." Figure 1 illustrates the synthesis of the identified groups to a measurement model for the constant energy-conscious driving.

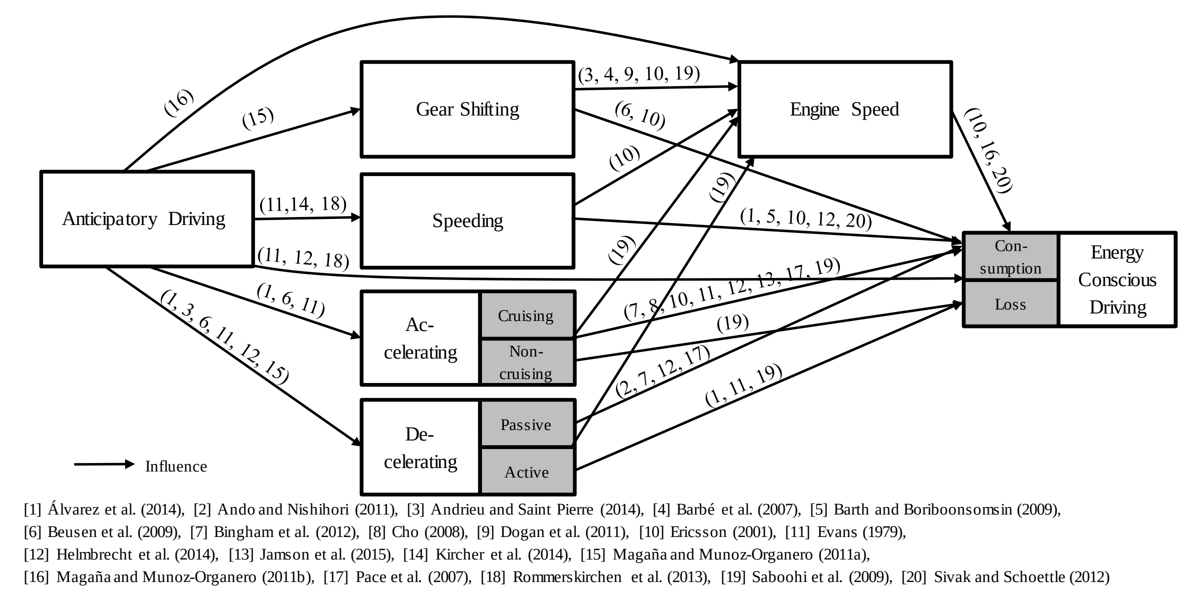

Figure 1. Green IS Measurement Model for Energy-Conscious Driving

Anticipatory driving influences engine speed (Magaña and Muñoz-Organero 2011b), gear shifting (Magaña and Muñoz-Organero 2011a), speeding (Evans 1979; Kircher et al. 2014), accelerating (Álvarez et al. 2014; Beusen et al. 2009; Evans 1979), decelerating (Álvarez et al. 2014; Andrieu and Saint Pierre 2014; Beusen et al. 2009; Evans 1979; Helmbrecht et al. 2014; Magaña and Muñoz-Organero 2011a), and energy-conscious driving (Evans 1979; Helmbrecht et al. 2014). *Gear shifting* influences the groups: engine speed (Andrieu and Saint Pierre 2014; Barbé et al. 2007; Dogan et al. 2011; Ericsson 2001; Saboohi and Farzaneh 2009) and energy consumption (Ericsson 2001; Magaña and Muñoz-Organero 2011b; Sivak and Schoettle 2012). *Speeding* influences the engine speed (Ericsson 2001) and the energy consumption (Álvarez et al. 2014; Barth and Boriboonsomsin 2009; Ericsson 2001; Helmbrecht et al. 2014; Sivak and Schoettle 2012). *Accelerating* causes energy consumption by cruising or non-cruising (Bingham et al. 2012; Cho 2008; Ericsson 2001; Evans 1979; Helmbrecht et al. 2014; Jamson et al. 2015; Pace et al. 2007; Saboohi and Farzaneh 2009). Accelerating influences the engine speed (Saboohi and Farzaneh 2009). According to the analyzed literature, non-cruising acceleration causes additional energy loss (Saboohi and Farzaneh 2009). *Decelerating* influences the engine speed (Saboohi and Farzaneh 2009). On the one hand, passive decelerating influences energy consumption by lowering the consumed energy (Ando and Nishihori 2011; Bingham et al. 2012; Helmbrecht et al. 2014; Pace et al. 2007). On the other hand, active decelerating causes additional energy loss (Álvarez et al. 2014; Evans 1979; Saboohi and Farzaneh 2009). *Engine speed* influences energy consumption (Ericsson 2001; Magaña and Muñoz-Organero 2011b; Sivak and Schoettle 2012).

Discussion

In the review, we identified six groups influencing energy-conscious driving: *anticipatory driving*, *gear shifting*, *speeding*, *accelerating*, *decelerating* and *engine speed*. In terms of the complexities of the factors considered in these groups, we conclude that energy-conscious driving is a multidimensional construct. Therefore, we discuss the articles which address several groups of measures, including one outlying group. Next, we debate merging similar groups into one. Consequently, we examine the commonalities and differences of related groups. Finally, we emphasize the dependencies between the groups to localize their positions in the measurement model.

Six of the 32 reviewed articles explore five or six measures, and we found one outlying article from Evans (1979). In 1979, he researched the effect of driver behavior on fuel consumption. Although, he did not specify "eco-driving," he measured the influence of speeding, accelerating, decelerating and anticipation of potential stop maneuvers on fuel consumption. This work is remarkable mainly because it addresses the impact of these factors and their dependencies. We extend these findings by adding anticipatory driving to a synthesized measurement model for the construct energy-conscious driving.

Dogan et al. (2011) and Magaña and Muñoz-Organero (2011a) apply each of the groups of measure. Dogan et al. (2011) gauge the measures to examine the impact of saving time as opposed to the goal of saving fuel while driving. However, these authors do not investigate the effect of the goal of energy-conscious driving on reducing fuel consumption in their feedback design. Magaña and Muñoz-Organero (2011a) develop an eco-driving assistant which models this driving style. They gauge variables included in each group of measures, and also use data from external sensors and a mobile device. They do not, however, interrelate the variables they measure, nor do they compile the measures into a single indicator. Andrieu and Saint Pierre (2014) use the measures to compare the difference between advice versus training on the eco-driving style. Additionally, they combine the measures to compute a global eco-driving indicator. For this, they define formulas for each golden rule of eco-driving, and do not consider the groups of measures directly. Barkenbus (2010) also does not interrelate the measures into an all-encompassing model. None of the articles presents an overview or the dependencies of the measures in total. Hence, a contribution to an extensive measurement model for energy-conscious driving is lacking.

The *engine speed* group depends on anticipatory driving, gear shifting, speeding, accelerating and decelerating. The dependency of the engine speed group is similar to the energy-conscious driving construct because the measuring constitutes a basis. Most literature depicts an influence between gear shifting and engine speed (Andrieu and Saint Pierre 2014; Barbé et al. 2007; Dogan et al. 2011; Saboohi and Farzaneh 2009). Several studies use rpm as an indicator for the design of eco-driving feedback (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Dogan et al. 2011). The lower the engine speed, the lower the consumed energy (Beusen et al. 2009; Hiraoka et al. 2009; Kaufmann-Hayoz et al. 2012). The lower the consumed energy, the more the driver drives in an eco-friendly manner. However, a lower engine speed is not necessarily synonymous with energy-conscious driving because active deceleration leads to lower engine speed and has the effect of additional energy loss with less energy consumption. However, this means transforming kinetic energy into not-yet-used thermal energy. Hence, the engine speed group indicates using rpm and influences the energy consumption part of energy-conscious driving, implicating splitting deceleration into active and passive. These results confirm our findings for the deceleration group. In total, our synthesized measurement model confirms the findings from Andrieu and Saint Pierre (2014), Barbé et al. (2007), Saboohi and Farzaneh (2009) and Beusen et al. (2009) by distinguishing between engine speed and gear shifting.

The *gear shifting* group depends on anticipatory driving and influences engine speed and energy consumption. The rules found in this group are vague and the literature provides no basis for a specific rpm at which to change gears (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Dogan et al. 2011; Ericsson 2001; Hiraoka et al. 2009; Jamson et al. 2015; Kaufmann-Hayoz et al. 2012; Saboohi and Farzaneh 2009). The optimal gear shifting range for eco-driving needs specific calculations for the individual transmission and vehicle properties (Ngo et al. 2013; Yang et al. 2002). Consequently, for each vehicle and transmission, the optimal point of shifting the gear can be calculated. Implicating the possibility for measuring an optimal gear shift for energy-conscious driving, and any deviation from this point causes additional energy consumption. Rpm measure the engine speed while gear shifting depends on a specific rpm. Accordingly, we extend these findings by considering engine speed and gear shifting as two different groups of measures.

All articles that measure the decelerating group also measure accelerating in a similar way (Álvarez et al. 2014; Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Barkenbus 2010; Beusen et al. 2009;

Bingham et al. 2012; Caulfield et al. 2014; Cho 2008; Dogan et al. 2011; Ericsson 2001; Evans 1979; Harvey et al. 2013; Helmbrecht et al. 2014; Kaufmann-Hayoz et al. 2012; Kircher et al. 2014; Magaña and Muñoz-Organero 2011a; Magaña and Muñoz-Organero 2011b; Pace et al. 2007). Further, both groups depend on anticipatory driving and influence the same group engine speed, and the same energy-conscious driving construct, more specific energy consumption and energy loss. Therefore, our data are in line with data presented in the literature, but acceleration and deceleration differ in the direction of their motion. We suggest considering accelerating and decelerating as two distinct groups of measures and have a look at in detail.

The *accelerating* group describes an increase in velocity and consists of cruising and non-cruising. In contrast to cruising, non-cruising might cause additional energy loss, such as friction losses due to spinning wheels. In contrast to prior studies, we take energy loss into account of the design of Green IS feedback (Barkenbus 2010; Barth and Boriboonsomsin 2009; Boriboonsomsin et al. 2010; Cho 2008; Helmbrecht et al. 2014; Neumann et al. 2015; Saboohi and Farzaneh 2009). The recommendations for acceleration are different: smooth acceleration (Barkenbus 2010; Barth and Boriboonsomsin 2009; Boriboonsomsin et al. 2010; Cho 2008; Helmbrecht et al. 2014; Neumann et al. 2015; Saboohi and Farzaneh 2009) and "swift acceleration" (Kaufmann-Hayoz et al. 2012). We follow the majority view, accelerating smoothly for energy-conscious driving. We extend the findings from Hiraoka et al. (2009) by a national independent measurement model.

The *decelerating* group describes a decrease in velocity and has two types: active and passive. Passive affects energy consumption while active (depressing the brake pedal) affects energy loss as not available for the system "car." We suggest avoiding active deceleration to achieve energy-conscious driving.

Energy-conscious driving depends on all groups of measures. These six groups of measures can be understood as first-order variables to explain the second-order construct energy-conscious driving. We found that energy-conscious driving comprises energy consumption and energy loss. According to Saboohi and Farzaneh (2009), non-cruising acceleration causes energy loss and, corresponding to Álvarez et al. (2014), Evans (1979), and Saboohi and Farzaneh (2009) by active deceleration. In contrast to these earlier findings, we take energy loss into account for an adequate measurement of energy-conscious driving. Thereby, Green IS enables to provide real-time eco-feedback on each group and their interplay to drive energy-efficiently. In addition, all other groups of measures influence engine speed, and this, in and of itself, influences energy-conscious driving, which might be seen as a transitive relation or control variable for the groups anticipatory driving, gear shifting, speeding, accelerating and decelerating.

Similar to the *engine speed* group, the *anticipatory driving* group has an outlying position as it is the only group of measure which influences all other groups and the energy-conscious driving construct. We have not identified a basis for measuring the anticipatory driving group, likely because the various factors included in this group are too vague. As a result, we consider anticipatory driving a pre-ordered variable.

Table 2. Found Groups, Structure Suggestion and Measurement Metrics

Group of Measure	Structure Suggestions	Measurement Metric(s)
Anticipatory driving	Pre-Order	none
Gear shifting	First order	position of gear for specific rpm
Speeding		km/h, miles/h
Accelerating		m/s^{-2}, accelerator pedal angle
Decelerating		m/s^{-2}, brake pedal angle
Engine Speed		rpm
Energy-conscious driving	Second order	l/100 km

We identify a synthesized measurement model for energy-conscious driving. Six groups explain the energy-conscious driving construct. In addition to these groups, the dependencies between the groups illustrate that three orders might structure the measurement model: pre-order, first order, second order. The pre-order contains all groups of measures that influence all other groups and energy-conscious driving. We assign the anticipatory driving measure to this order. The first order contains all groups of measures that influence energy-conscious driving, and one or more of the groups of measure except anticipatory driving. Included in the first order are gear shifting, speeding, accelerating, decelerating and engine speed. The second order contains the measured construct; this is energy-conscious driving. Table 2 illustrate the structuring and the found measurements.

Conclusion, Limitations and Further Research

We found not one single energy-conscious driving measure. Instead, a group of six measures—anticipatory driving, speeding, gear shifting, accelerating, decelerating, and engine speed—explain the energy-conscious driving construct. We introduce an extensive synthesized measurement model in which we combine the energy-conscious driving construct with the identified six groups into a descriptive Green IS measurement model. By studying the interplays and the groups themselves, we developed a more precise overview of the construct energy-conscious driving. Green IS research can use the findings for evaluating different designs of eco-feedback and studying eco-driving in detail. Further, this research explains the necessity of energy consumption and energy loss as parts of energy-conscious driving. Therefore, we will extend the found literature with the operationalization of energy-conscious driving in our future work to illustrate Green IS eco-feedback. Practitioners can use this model to implement specific eco-feedback systems for improved user performance and user experience.

Due to its preliminary state, this research has limitations which we will address in future research. The synthesized measurement model needs validation. Therefore, we plan a two-step approach to validate the measurement model in a formative manner according to Bliemel et al. (2005), and a laboratory experiment to measure the influence of the identified groups to energy-conscious driving in a reflective way. The engine speed group identified different optimal values which might be due to the dependency between the engine speed and the environment. Future research in the field of Green IS can obtain concrete values for a universal formula. The presented measurement model is limited to measures that can be influenced by human behavior and focuses on measures of a primary task. Secondary or tertiary tasks which influence energy consumption, such as using air conditioning, radio, or multimedia, need more specific research. Moreover, non-human influencing factors such as drag coefficient or tire pressure play a role in energy consumption.

The measure of the anticipatory driving group is still too vague and requires further research. It might turn out to be a pre-ordered variable for the five groups of *engine speed*, *gear shifting*, *speeding*, *accelerating* and *decelerating*. To extend this research, we suggest a two-step approach first by exploring non-primary driving task influencing factors for these groups and second to compare these factors with the anticipatory driving group. Further, examining the identified measures with experiments. Furthermore, we evaluate whether the found measures can be used for designing eco-feedback for energy-conscious driving. Green IS enables eco-feedback by structuring the findings in a more comprehensive model containing all measures and their interplay. Related questions might be, does the measurement of energy-conscious driving change through this innovation and if so, how does it change? Moreover, on this basis, Green IS eco-feedback can be designed and implemented to evaluate human behavior while driving and giving the driver more specific information.

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